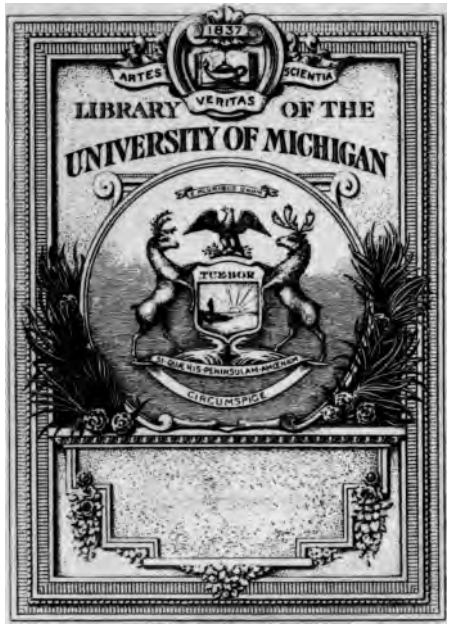
THE CAUSE OF GEOLOGIC PERIODS

BY C. A. M. TABER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BY
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BOSTON
GEO. H. ELLIS CO., PRINTERS, 272 CONGRESS STREET
1907

PREFACE.

THIS essay contains a summary of my former publications, the earliest dating as far back as 1881. At that time my first attempt was made to explain, from a marine standpoint, the causes that have brought about the great climatic changes that have left such positive traces on the land surface of the globe.

At the beginning of my endeavor my equipment consisted in such marine knowledge as I had been able to acquire during long whaling voyages, which extended over the Atlantic, Pacific, and Indian Oceans. These searching voyages began in 1839 and ended in 1862. The familiarity thus gained of the ocean world enabled me to avoid the many errors then advanced and to make considerable progress in the direction I have pursued.

My marine experience having early taught me to view the earth in its wholeness, consequently it was easy to see the manner in which the great prevailing winds, in connection with the distribution of lands and seas, have been able to cause great periodical changes of climate; while during later years I have given more attention to geological records, and find that they coincide with the marine world from which I derived my earlier impressions. So it was through this wide field and slow process of study that I have sought to comprehend the manner in which the low-land regions of northern continents and large islands have been built up, and how the

physical geography of the earth of this age has been obtained. And, while continuing in this endeavor, during the last spring and summer I have been able to give the subject further study, which has enabled me to make important additions which were required to confirm my previous explanations and render a more efficient exposition of the manner in which solar heat, through the peculiar arrangement of lands and seas, in connection with the great prevailing currents of the air and ocean, shows that the Designer of our planet intended it for a periodical world millions of years ago, and probably intends it to proceed on its interesting rounds for ages to come.

C. A. M. TABER.

WAKEFIELD, MASS., September, 1907.

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WHILE viewing the order of succession of the stratified formations of the crust of the earth in order to ascertain how large portions of the extensive low lands of the northern temperate zone have been built up, it is essential to find out Nature's way of proceeding to accomplish work of such magnitude.

In this effort we find that coal and salt, although necessarily existing in separate localities, are known to have been deposited during the same periods of time, and are found to occur in almost every geologic age. Yet they have required in their formation great changes of climate and also of sea-level. So our main object will be to explain how such climatic changes and high and low stages of ocean water have been brought about.

With this endeavor we will state that at the breaking up of the last glacial period, according to the researches of reliable geologists, the ocean waters of the northern hemisphere were greatly augmented, so that all of the low lands of Europe, Asia, and North America were flooded by the sea. This submergence was caused through the superior weight of the heavy ice-sheets that burdened the northern continents and islands, which at the perfection of the ice age covered a far greater area than the glaciated lands lying south of the tropical zone.

Therefore, when it is considered that the frozen water contained in the glaciers that so widely covered the land was supplied from the ocean, it will be seen that the seas of the

southern hemisphere, possessing nearly twice the area of the northern seas, also furnished nearly double the quantity of water necessary to form the glaciers. Consequently, the weight thus transferred from the southern seas to the northern hemisphere caused the earth's centre of attraction to move northward in proportion to the weight transferred from the southern hemisphere into the northern. Under such conditions a portion of the remaining waters of the southern seas were attracted northward, to still further swell the waters of the northern seas. Thus the southern seas were greatly reduced in depth, and also so much lessened in area that the bottom of the Cape Horn channel was raised above the level of the sea and the independent circulation of the southern oceans destroyed.

Such being the conditions at the perfection of the ice age, the arrangement of lands and seas in connection with the great prevailing winds was favorable for changing an age of coldness into a period of mildness.

To bring about this great climatic change, the strong winds of the southern-westerly wind-belt in their wide sweep over the South Atlantic forced the surface waters away from the eastern shores of Southern South America and the obstructed Cape Horn channel, and so onward into the Southern Indian Ocean, thus causing a vast low sea-level in the southern latitudes of the South Atlantic, so the waters of the high sea-level abreast Brazil, caused by the south-east trade winds, were strongly attracted southward to the vast low sea-level of the said South Atlantic.

This attraction of tropical surface water southward was much assisted by the north-east monsoon during the summer of the southern latitudes, and also by the convective currents, until the increased volume of tropical water flowing into the high southern latitudes began the slow process of

melting and breaking up the icebergs and ice-floes of the South Atlantic and antarctic seas.

In addition to this great movement of tropical water into the high latitudes of the South Atlantic, the Agulhas current, which is a continuation of the great equatorial stream of the Pacific and Indian Oceans, flowed with increased velocity into the vast low sea-level of the South Atlantic and South-western Indian Ocean.

This great current of tropical water even at this age, with a high stage of southern ocean water, flows with a considerable stream from the high level of the equatorial stream of the Pacific and Indian Oceans southward through the Mozambique channel, and so onward around the Cape of Good Hope into the low sea-level of the South-eastern Atlantic, although the Cape Horn channel, opening widely from the South Pacific, largely replenishes the surface water blown from the South Atlantic by the strong westerly winds of to-day during a high stage of southern ocean water. Thus it will be seen how greatly increased in velocity the Agulhas current must have been with the Cape Horn channel obstructed. Yet at the same time it should be considered that the low stage of southern ocean water had reduced the capacity of the Mozambique channel, and it may have been entirely closed while the Agulhas bank was brought above the level of the sea, and so extended the shores of South Africa southward. In that case the Agulhas current followed the east coast of Madagascar from the high sea-level of the equatorial stream abreast Africa, and in connection with the convective currents carried a great quantity of warm tropical water well into the southern latitudes of the South-western Indian Ocean.

Meanwhile New Zealand on account of the low stage of water in the southern hemisphere was united to the antarctic lands. The several groups of islands situated south

of New Zealand indicate a sea of moderate depth in that direction as far as the islands extend. The sea south of this region is supposed to possess a depth of 1,000 to 2,500 fathoms. Yet the bottom of this sea was laid bare, so the strong westerly winds drifted the surface waters away from the extended lands, and so caused a low sea-level along the New Zealand shores, which attracted the south-western tropical Pacific water well into the antarctic latitudes. In fact, this extension of land was necessary in order to complete the arrangements required for subduing the ice of a glacial period.

In considering the probability of Australia having been united to the antarctic lands, it is necessary to obtain the depth of water between the southern shores of Tasmania and Royal Company Islands, and from thence to the Macquarie Islands. Should such soundings not exceed much over 1,700 fathoms, it would show that the ocean bottom was above the sea-level during a low stage of southern ocean water. The depth of the sea as represented on the charts of to-day is given as ranging from 1,000 to 2,000 fathoms, which correspond with the depth of the Cape Horn channel. Therefore, New Zealand and South America were both united to the antarctic lands during a low stage of southern ocean water, and it appears that, according to the soundings south of Australia, it was united to New Zealand in the region of the Macquarie Islands. Thus both united lands were connected with the antarctic shores at the perfection of an ice age, because without such connection the ice-sheets that so widely covered the continents and islands of the globe could never have been subdued. But with the connection of the lands above named with the antarctic shores the strong prevailing winds of the southern-westerly wind-belt would cause a vast low sea-level to the leeward of the extended lands, and

so attract the tropical waters of the South-western Pacific well into the antarctic latitudes, and so melt the ice from the seas and shores of that extensive region.

During the time that the southern ice was being subdued in the manner set forth, the glaciers that gathered on the tropical lands had disappeared, and the augmented oceans of the northern hemisphere had made some progress in reducing the heavy glaciers that burdened the lands of the northern latitudes.

The tropical waters of the augmented Gulf of Mexico had melted the ice-sheets from the submerged low lands in its vicinity, and had flowed over Florida and the low coasts of Georgia and Carolina. Moreover, the Red Sea was an enlarged strait, connecting the high sea-level of the tropical Indian Ocean with the enlarged Mediterranean, whose shores, according to the researches of Professor Prestwich, have been deeply submerged. So the high lands of Northern Africa must have been reduced to a group of islands.

Under such conditions the tropical waters of the high sea-level of the equatorial stream of the Indian Ocean accomplished great work, after passing through the Red Sea, in breaking up the ice-sheets that covered Sahara and other Northern African lands. So, during the time of the highest stage of the northern ocean waters, large volumes of tropical Indian Ocean water passed over the lowest lands of Sahara, and added much warmth to the equatorial stream of the Atlantic, which flowed through the Caribbean Sea and enlarged Yucatan channel in greater volume than at this age; and, on entering the Gulf of Mexico, that portion of the current that turns westward and flows along the west shores of the gulf northward was not attracted eastward, as is the case to-day, but continued on its northerly course over the submerged lands of Texas and Mississippi

valley, and this warm flow of tropical water was to perform progressive work while subduing the ice that obstructed its progress northward.

To facilitate the thawing process, the only continuous land stretching northward from Mexico during such times was the high ridges of the Rocky Mountains and Sierra elevations, the former range extending northward to the arctic circle, and at that icy period the whole elevated region was heavily glaciated. With this arrangement of lands and seas the westerly winds, as fast as the ice was melted from the submerged low lands, forced the surface waters away from the Rocky Mountain high lands, and thus caused a low sea-level, and so attracted the high-level Gulf of Mexico waters northward whenever the sea became free of ice. So in due time a warm shallow sea covered the Mississippi valley, Great Lake, and Hudson Bay region, the warm gulf water extending into the polar latitudes, which on account of its general shallowness caused the westerly winds to be much more effective in creating a low sea-level than could be obtained on the deeper Atlantic.

Therefore, the low sea-level of the shallow sea had great attraction for the waters of the high sea-level of the Gulf of Mexico. Consequently, a vast thermal current, several times larger than the present Gulf Stream, passed over the Mississippi valley, and onward over the Great Lake and Hudson Bay region into the Arctic Ocean.

This great flow of tropical water into the Arctic Ocean was sufficient to gradually melt the heavy ice-floes from the polar seas, and also the glaciers that spread over the low portions of Europe and Northern Asia, which at that period were below the sea-level of the augmented northern oceans, Siberia being so widely submerged that the arctic seal had access to the waters of Lake Baikal; and it is

reported that their descendants still occupy the waters of the elevated lake, which is now situated a thousand miles inland because of the shrinkage of the arctic seas after the breaking up of the ice age.

The thermal waters that so widely submerged the low lands of the high northern latitudes during late Quaternary periods did not remain at a high stage so long as the flooding waters of the earlier mild periods, according to geological records, when heavy marine deposits must have required much time and a warm tranquil sea, and the oceans, as is always the case, were well adjusted to the earth's centre of attraction.

During these high stages of northern ocean water the petroleum beds had ample time for the growth of marine matter such as is required for their formation, and calcareous life obtained a long period of submerging thermal seas favorable for its growth, and also in possession of a much wider area than is afforded by the high stage of southern ocean water in the southern hemisphere to-day.

But the vast southern oceans appear to present a much larger field of barren ocean bottoms than obtain on the bottoms of the oceans of the northern hemisphere. Still, the southern ocean during a low stage of water might present a more favorable view in regard to its stratified low lands now submerged.

Still, it is probable that the southern oceans in their low stage would show much smaller areas of low stratified lands than obtain in the extensive low lands of Europe, Asia, and North America, which geology proves to have been built up periodically on the unstratified primary rocks.

The first movements of the high stage of northern ocean water southward since the glaciers of the ice age were sub-

dued was probably caused by the prevailing winds of the southern-westerly wind-belt blowing the surface waters of the sea away from the leeward coast of Southern South America, and the united islands of New Zealand and other united groups of southern ocean islands, and so causing extensive low sea-levels, sufficient to attract large volumes of water from the high sea-levels of the equatorial seas, such as are obtained by the trade winds abreast Brazil in the Atlantic and abreast Northern Australia in the Western Pacific Ocean, and also against the east coast of Africa and the east coast of Madagascar in the tropical Indian Ocean.

Under such conditions it should be considered that for a long time after the glaciers of the ice period were melted, such ocean waters as were attracted from the northern seas into the high southern latitudes, only a small portion could be retained in the southern seas for the reason that a wide flow of Atlantic water fed by the Sahara Sea passed through the Caribbean Sea and enlarged Gulf of Mexico, and onward over the submerged Mississippi valley, Great Lake, and Hudson Bay region into the Arctic Ocean, and so retained the high stage of northern ocean waters to a great extent, especially while the waters of the vast Sahara Sea were replenished from the thermal waters of the Red Sea, and thus were able to supply the equatorial stream of the North Atlantic with sufficient warm water to flow the low lands of North America, Europe, and Siberia, and also maintain a mild temperature throughout the arctic region.

But at length it happened that the slow retirement of the northern ocean water southward caused the Red Sea to be separated from the Sahara Sea. So the shallow waters of the latter sea were soon drifted into the equatorial stream of the Atlantic by the prevailing easterly winds, except such

of the waters as were empounded in the shallow basins where they were soon evaporated. Thus, through the disappearance of the Sahara Sea, the northern hemisphere was deprived of a great source of warm sea water, which had proved efficient for subduing the heavy glaciers that burdened the northern continents and islands during the cold periods.

Meanwhile, besides the discontinuance of the great currents that set northward over the Mississippi valley, Great Lake, and Hudson Bay into the Arctic Ocean, it appears that, when the northern ice was subdued, it happened that such of the high stage of northern ocean waters as were attracted into the high southern latitudes could not be returned by gravity for the reason that the weight of such waters changed the earth's centre of attraction in the same proportion. So the process went on at a slow rate until the submerged northern low lands were raised above the level of the sea. Thus the weight and immobility of the great northern continents and islands would not admit of the earth's centre of attraction being moved further southward. Therefore, the surplus waters that were moved from the northern seas into the southern latitudes by the prevailing winds, while assisted by the convective currents, were mostly returned to the northern seas by under-currents, and to a certain extent by drift-currents which are maintained in the South African and Peruvian currents.

Under these conditions of oceanic circulation the waters of the globe have retained nearly the same sea-level that they now possess for several thousand years, and the climate, as far as we know, has been very slow in whatever change it may have made during the last two thousand years. But it is generally thought that there has been a greater fall of snow in Palestine during the last century than obtained

during the century following the birth of Christ. It is also thought that fruit is more liable to receive injury from frost than in earlier years. Yet it is probable that there will be no greater change of climate during the next two thousand years than has happened during the last twenty centuries. But it is evident that the present position of the ocean waters are unfavorable for a long continuance of a mild period, because it is impossible, with the southern seas augmented and the northern seas at a low stage, for the waters of the tropical oceans to gain access to the seas of the high latitudes in sufficient volume to maintain a mild climate for a lengthy period.

For instance, the present low stage of the northern oceans has reduced the tropical currents of the Gulf of Mexico to a narrow and tortuous stream setting through the Florida channel with a volume several times smaller than obtained when the northern oceans were augmented and the great Sahara Sea supplied the tropical Atlantic and Gulf of Mexico with thermal water from the equatorial stream of the Indian Ocean through the Red Sea, so this tropical water was ample to flow over the Caribbean Sea and Gulf of Mexico, and so onward over the Mississippi valley, Great Lake, and Hudson Bay regions, so that sufficient tropical surface water entered the temperate and arctic latitudes to subdue the accumulated ice of a frigid period.

At the present time, although the Gulf Stream opens directly into the great low sea-level which is mostly caused by the strong westerly gales of the winter season forcing the surface waters of the Atlantic away from the North American coast from Florida to Labrador, yet the Florida channel so contracts the Gulf current that it is capable of disposing of only a portion of the large collection of surface water which is forced by the north-east trade winds across the Atlantic

to the great high sea-level to the windward of the Caribbee Islands.

This fact becomes plainly visible to a person who may be interested in such matter while voyaging over that portion of the Atlantic from the Madeiras to the West India Islands.

For the first fifteen hundred miles of the passage the surface waters are impelled by the north-east trade winds toward the West India Islands without much apparent resistance or unusual disturbance until nearing the longitude of Cape St. Roque, where a vast high sea-level has been obtained from which there is no easy outlet. Consequently, the impelled waters begin to rebel against the forceful winds, and thus cause a remarkable commotion in the shape of tide-rips and white-capped ripples, which extend from the equator northward to the latitude of 19° north, thus crossing the central portion of the north-east trade-wind belt, with a breadth of about three hundred miles. There is a vast sluggish current setting northward from the disturbed region into the temperate latitudes; but the sea-level of the North Atlantic in these longitudes possesses only a moderate attraction for the agitated tropical waters, so that the only perceptible reason why the surface waters of this disturbed portion of the Atlantic do not flow peacefully along into the Caribbean Sea, and so onward into the Gulf of Mexico, is because of the narrow outlet of the Florida channel, which opens on the great low sea-level of the North Atlantic. Thus it is apparent that the North Atlantic trade winds are still performing sufficient work for the maintenance of a mild climate in the temperate latitudes of the North Atlantic, such as they have maintained since the Sahara Sea disappeared. But we now see the constant operating of the north-east trade winds mostly lost through the lack of capacious channels leading to the low sea-levels of the high northern latitudes.

Therefore, under the present conditions the Gulf Stream and all other sources of heat fail to carry sufficient warmth into the northern temperate and arctic latitudes to prevent a slow increase of coldness. Meanwhile the same tendency to a slowly lowering temperature is going on in the southern hemisphere, because its augmented seas have filled the Cape Horn channel, and so prevent the westerly winds from creating a vast low sea-level in the high latitudes of the South Atlantic, competent to attract the thermal waters of the tropical Atlantic and Indian Oceans in sufficient volume to prevent the ice from gathering on and around the antarctic shores. Furthermore, the present high stage of southern ocean water has separated New Zealand and Australia from the antarctic shores, thus causing a wide sea that prevents the westerly winds from forming such capacious low sea-levels to the leeward of their shores as were obtained when the southern oceans were reduced to a low stage, and a much greater volume of tropical water was attracted into the high southern latitudes than are attracted to the same latitudes by the inferior low sea-levels of to-day.

Therefore, under the present conditions the strong winds of the southern-westerly wind-belt, instead of causing ample low sea-levels to attract the tropical surface waters into the high southern latitudes, are at the present time constantly drifting the surface waters of the southern oceans around the globe, and thus turning away the tropical surface currents setting southward, and so preventing them from directly entering the high southern latitudes in great volume. Consequently, it is evident that the present augmented condition of the southern oceans is every way favorable for a slow increase of cold.

The present natural arrangements for causing a slow increase of coldness in the high southern latitudes is shown

where the tropical waters of the high sea-level abreast Brazil are attracted southward along the South American coast to the low sea-level abreast Argentine and Patagonia. These warm surface waters in their southern movement have the aid of the convective currents and also the drifting force of the strong north-east monsoon during the southern summer. But on entering the westerly wind-belt a portion of the warm surface waters are drifted eastward over the ocean, and returned to the equatorial latitudes through the South African current, while a larger portion flows southward with a constant lessening force along the low sea-level abreast Argentine and Patagonia. Meanwhile its southern progress is retarded, and seemingly ended, on meeting the Cape Horn drift-current. Still, it is able to soften the climate somewhat along the eastern coast of Patagonia and also the bleak shores of the Falkland Islands. But the larger portion of the Brazil water, while on the southern half of its passage southward, is drifted eastward over many degrees of longitude by the strong westerly winds until lost in the cold, icy drift-currents that pass through the Cape Horn channel, and at the same time so much of the Brazil water as contains the convective currents is attracted slowly southward into the ice-strown seas until it has gained sufficient density to sink into the lower depths of the sea, and thus supply the cold under-currents that set northward into the temperate and tropical latitudes, so that the lower depths of the equatorial seas have obtained antarctic temperatures.

The same tendency for lowering the temperature of the southern latitudes is being carried on to-day, where the tropical surface currents move southward from the equatorial seas along the western sides of the Pacific and Indian Oceans, while being slowly attracted into the seas of the

high southern latitudes to inefficient low sea-levels. The tropical waters of the Indian Ocean are attracted southward along the east coast of Africa to a slight low sea-level of the South-eastern Atlantic, which is partly caused by the south-east trade winds of the South-eastern Atlantic which blow from the region of the Cape of Good Hope, and so along the South African shore northward to the equator. But, as the distance from the coast increases, the wind blows more from the south-east, and, after passing St. Helena, the winds gradually lose their force while nearing the equatorial calm belt. Still there is a considerable portion of the south-east trade wind that passes west of St. Helena that serves to cause a high sea-level abreast the coast of Brazil, as has been previously pointed out. So it happens that the tropical water that follows down the Mozambique channel and along the South African coast, and, after passing Cape Agulhas, gradually loses its force, and, before passing the meridian of Greenwich, mostly turns southward, and so lost in the cold southern ocean waters where the strong westerly winds drive the gigantic waves from west to east across the Southern Indian Ocean, and so past the separated lands of New Zealand, which now afford an inferior low sea-level for attracting the tropical Pacific waters southward. Consequently, the scanty tropical water entering the high southern latitudes affords a small obstruction to the great drift-current of cold water that encircles the globe in these latitudes from west to east during high stages of southern ocean water.

This independent circulation of ocean water in the seas of the high southern latitudes is always favorable for the increase of cold, as is the case to-day. But when a low stage of southern ocean water, which always succeeds a cold period, is brought about, New Zealand, with the southern

islands in these longitudes, will be united to the antarctic shores, and a great change occur in the circulation of the southern oceans, because the strong westerly winds would force the surface waters of the sea away from the leeward shores of the united islands, and so cause a vast low sea-level that would attract the tropical western Pacific waters southward in great volume well into the antarctic seas. Thus it will be seen that, with the Cape Horn channel closing at the same time, a period of mildness would be brought about. And, while we consider the matter, it seems wonderful that the lands and seas of the southern hemisphere, in connection with its great prevailing winds and convective currents, are so completely arranged for bringing about long periods of mildness and coldness, besides periods of submergence of low lands, such as the low lands of the southern hemisphere are being subjected during the present high stage of southern ocean water.

As this is a subject of great importance in the geological history of the earth, therefore it is necessary to be explicit in our explanations, so we will further say that the submerged land south of New Zealand occupies an important position for the reasons that we have previously pointed out.

The islands that appear above the submerging sea in that region are the highest of the mountains rising from their submerged base, probably about ten thousand feet before appearing above the surface of the present sea-level. But the ocean south of the islands requires a depth of over two thousand fathoms. The deepest water reported by the exploring ship "Discovery" was in latitude 62° 50′ south and longitude 130° east. Soundings were taken giving depths of 2,500 and 2,300 fathoms, respectively, and, further south, 1,750 fathoms were shown within two hundred miles from Adelie land. The soundings taken were few on account of

the floating ice. So it appears that it requires a depth above two thousand fathoms of water during a high stage in order for the full development of a succeeding cold period. For, when the submerged land appeared above the level of the sea, the progress of a glacial age would end. With such conditions New Zealand would extend southward from its northern shores directly across the southern westerly wind-belt and connect with the antarctic shores, as we have previously asserted. Such conditions would entirely break up the independent circulation of the southern oceans, while the low sea-level caused by the westerly winds forcing the surface waters of the sea away from the extended land would cause the tropical waters of the South-western Pacific to be attracted southward in great volume as far as the land extended in that direction, and so prevent all increasing coldness and cause a mild climate to prevail even in the antarctic latitudes.

This provision, with the Cape Horn channel obstructed in the manner that we have previously explained, would cause a mild climate to prevail along the antarctic shores wherever the southern ocean waters penetrated, and the mild climatic conditions would continue as long as the low stage of water remained in the southern hemisphere. And the mildness would continue with a slowly lessening warmth until a succeeding high stage of southern ocean water gave an independent circulation to the southern seas, and so cause a slowly lowering temperature such as obtains to-day, which will eventually end in an age of coldness.

It may be thought a broad assumption to assert that a great body of sea water evaporated from the vast southern oceans and deposited on the great northern continents and islands in the shape of snow and ice would change the earth's centre of attraction in proportion to the weight thus trans-

ferred from the high southern latitudes to the high northern latitudes; but there appears to be no other explanation to account for the lands of the northern continents being submerged by the sea on the breaking up of an ice age, for the reason that the ocean waters must always be nearly adjusted to the earth's centre of attraction. Such being the case, the ocean waters of the high southern latitudes must have been brought sufficiently low for the submerged lands south of New Zealand and Cape Horn to be raised above the sea sufficient to prevent the independent circulation of the great southern ocean. Therefore, the gathering of ice would necessarily continue on the great northern continents until it was accomplished, and the westerly winds were able to cause low sea-levels to the leeward of the emerged lands sufficient to attract the tropical waters of the Western-southern Pacific and the South-western Atlantic well into the antarctic seas, and so cause a mild climate in the high southern latitudes, in the manner we have repeatedly shown.

While seeking to explain what has taken place on the earth to cause the geological climates, there is considerable difficulty in bringing the mind to realize the correct proportions of the lands and seas, especially in their vertical measurements in comparison with their horizontal extension. We get a fair representation of an ocean or continent by the space it occupies on a globe three feet in diameter. But, when we attempt to ascertain the depth of the ocean or the height of a mountain, their measure is too small for our senses to discern.

Still, to render the subject more comprehensible, we will imagine a globe for representing the earth sixteen feet in diameter, and this diameter supposed to measure about eight thousand nautical miles. This globe would be about the smallest size suitable to render the subject explainable, and show only approximately the changes that have been

wrought in the earth's centre of attraction by the heavy ice-sheets of a glacial age and their ability to change the sea-level. Thus on the diminutive scale of a globe sixteen feet in diameter it appears that, should the earth's centre of attraction be moved northward from its present position about two and one-half nautical miles because of the preponderant weight of northern glaciers, this movement would be equal to 16,000 feet, which would be sufficient to cause the sea-level at the north pole to rise about the same number of feet, while the polar ocean waters of the southern hemisphere would be reduced accordingly. This raised sea-level at the north pole would be lessened with the decrease of latitude, but the reduction of sea-level would be small with the decrease of latitude. Yet, while the latitude decreased, the reduction of sea-level increased until the equator was gained, which marked the latitudinal position of the earth's centre of attraction at that time, which was about sixteen thousand feet north of the earth's centre of attraction and equator of to-day. Thus this narrow belt, with a width of about two and one-half nautical miles, equal to about one-sixteenth of an inch measured on a globe sixteen feet in diameter, represented a zone over which the equator has passed back and forth during the mild and frigid periods of the geological ages. The narrowness of this equatorial zone shows how little the earth's centre of attraction was affected by the ice of a glacial age, and it is surprising to learn how so small a movement in the earth's centre of attraction could cause such great changes in its crust as has taken place according to geological records. Still, it may be that the earth's centre of attraction may have been moved northward by the weight of the northern glaciers over sixteen thousand feet, as it would depend on how low the level of southern ocean water would be necessary for uniting

New Zealand to the antarctic lands, and also reducing the ocean waters south of Cape Horn sufficient to stop the independent circulation of the southern oceans, for it is certain that the accumulation of ice would continue until it was accomplished.

The deposits of matter of marine growth during high stages of northern ocean water in different latitudes might afford reliable information on the subject, and elevated basins like Salt Lake and the remains of ancient beaches appear to give reliable information in regard to high stages of northern ocean water.

The flooding of the low lands of the northern continents and islands at the breaking up of the glacial age caused great changes in the geography of lands and seas in both hemispheres. In the northern hemisphere at Panama the rise of sea-level in the Caribbean Sea and Pacific Ocean was probably above two thousand feet, and at Tehuantepec the rise of sea-level must have been nearly four thousand feet above the present sea-level. As the rise of sea-level increased with latitude, the greater portion of Mexico must have been submerged where the land was not over seven thousand feet above the sea-level of to-day. This is proved by the abundant deposits of salt, gypsum, and marble throughout the plateau and Sierras.

The uniting of the Pacific and Atlantic continued through the high stage of the northern seas, but there was no great exchange of water, as both sea and ocean were at a high sea-level, caused by the prevailing winds, which blow from the north-west in the Pacific and from the eastward in the Caribbean Sea, and at the same time the high lands of Mexico and the Rocky Mountains separated the North Atlantic from the North Pacific nearly to the arctic circle.

So the changes of sea-level caused in the manner we have

endeavored to explain have repeatedly been able to submerge and emerge all the low lands of Europe, Asia, and North America, and thus account for the vast marine deposits made during high stages of northern ocean water, and for the numerous traces of ancient beaches on elevated lands, and also the periodical manner in which the stratified low lands of Europe, Asia, and North America, have been built up while undergoing the required changes of climate and submergence and emergence necessary for the formation of the vast salt deposits and limestone formations and the upbuilding of the coal measures.

The building up of such lands according to the records derived from the stratified deposits of the coal measures required a long mild period to furnish vegetative matter to form a seam of coal, and then a succeeding age of freezing temperature in order to cover the whole region with glacial débris, consisting of sand, gravel, conglomerate, and clay. This covering was sufficient to protect the coal that remained after the heavy ice-sheets which covered the great northern continents had attracted sufficient warm water from the tropical and southern oceans to melt the burden of ice and inundate all the low lands of the northern temperate and arctic latitudes. So the depth and quietness of the submerging thermal waters were favorable for the formation of shale, limestone, and also the growth of petroleum beds and other marine matter. But after a long period of time the high stage of northern ocean waters were slowly attracted southward to swell the southern oceans to a high stage, in the manner we have previously set forth.

Thus, while the northern oceans were being reduced to a low stage, the rivers from the high-land regions emptied their clayey waters into the disturbed shallow retiring

sea sufficient to form a stratum of fine clay suitable for the growth of a seam of coal, and also a necessary protection for the rank marine growth of the petroleum beds, which otherwise would be exposed to the succeeding long atmospheric period necessary for the growth of a seam of coal.

Thus it will be seen that the building up of the northern low-land coal measures required many ages of mild weather, and each age separated by a period of cold, followed by a long period of submergence beneath thermal waters suitable for the marine growth of limestone and petroleum beds, which occupy large areas in the vicinity of the low-land coal measures. The building up of the coal measures must have required several millions of years, and the work seems to have been carried on with considerable regularity. Yet during the late geological ages the warm submerging periods seem to have failed to leave such heavy deposits of warm aquatic growth as was the case in the earlier periods; for it appears that the work of the late ice periods show a greater production of crystalline débris from glacial action than is found in the more ancient glacial deposits.

In order to account for the building up of the stratified shores that surround the Great Lakes within the great basin, and also show why during such times the lakes have been able to maintain great depths in portions of their areas, we will say that during the early geological ages, as far back as the primary periods, the high stages of northern ocean water submerged the Great Lake basin, and on the retirement of the said water into the southern oceans the sea water confined in the basin began to lessen through evaporation, and in consequence heavy deposits of salt were laid down on the shallow portions of the basin, while the briny waters were being slowly diminished. Yet it seems that the brine in the deepest portions of the basin

remained in solution because the enlarged surrounding area of land, caused by evaporation, retained sufficient water from rain-fall to replenish the brine, but the water so furnished was scanty for the reason that such lands were mostly covered by bare limestone and salt deposits.

Thus, when the following glacial period covered the limestone and salt deposits of the basin with snow and ice, the adjacent high-land northern glaciers were attracted to the lower portions of the basin, and so covered the ice-cold brine of the lower depths with heavy ice-sheets until the whole basin was filled with ice. So the glaciers of the northern high lands had a level field of ice to pass over while moving southward, and so were able to spread their débris over the heavy vegetable growth of the coal fields of Pennsylvania and West Virginia, and also to afford ample covering of morainic débris over the ice-covered Great Lake basin. Therefore, when the following high stage of warm ocean water appeared in sufficient volume to submerge the Great Lake basin and subdue the ice, the morainic débris remained and covered the shallow areas of the basin, while the brine remained in the lower depths. So the shallow areas gained a thick stratum of salt in addition to the morainic deposit, and in addition, during the period of thermal water submergence, a stratum of limestone was added to the shallow portions of the basin, while the lower depths were not favorable for the growth of marine matter. So it appears that, while the shallow portions of the basin were built up, the deeper portions received small additions. Thus it happened that during the early geological periods the process above described was repeated many times. Still there was no fresh-water lakes until the salt deposits necessarily diminished with the filling of the basin, so that limestone and morainic débris was the principal formation of the upper strata, which was

favorable for retaining the rain-fall that had increased, because the Sierra and Rocky Mountains that had obstructed and condensed much Pacific Ocean water vapor were much reduced during cold periods by glacial action. Still there never would have been fresh-water lakes discharging water from the basin, had the extensive shores that now bound the Great Lakes never been built up in the manner above described, and thus formed wide land areas for the storage of rain-fall, and so preserved sufficient fresh water, not only to help supply the water evaporated from the Great Lakes, but also a sufficient surplus for their outlets.

The large area of land that conserves the rain-fall that supplies the springs and streams that flow into the Great Lakes above Niagara Falls at this age probably occupies double the area of the Great Lakes which it surrounds. And because of the great capacity of this land for the storage of water it is able to store up a large portion of the rain-fall, and so protect it from being evaporated by exposure to the atmosphere and the sun's rays, while that portion of the basin covered by the lakes loses as much or more water from evaporation by exposure to winds and solar rays than it receives from snow and rain-fall. Consequently, the lakes alone cannot supply water for the Niagara Falls and Chicago canal. Therefore, the water passing out of these outlets is from the rain-fall that has been stored in the lands of the Great Lake basin.

Thus it appears that the periodic growth of limestone and other marine matter in submerging thermal seas, and the great accumulations of salt from evaporation of sea water, and the great deposits of morainic débris during glacial periods have increased the land areas of the great basin sufficient to protect enough rain-fall from evaporation to supply the great outlets at Niagara and Chicago.

Yet, while there has been a large periodical increase of land, during the later geological periods there has been a corresponding decrease in the lake-water areas. Thus it appears that during the glacial periods of the future the land areas of the great basin will continue to increase, and consequently augment the flow of water from its outlets. Yet at the same time the lakes will necessarily decrease in size, and so diminish the evaporation during the future low stages of ocean water in the northern hemisphere. Still, the loss of water vapor so caused would have small effect on the rainfall of the Great Lake basin, as the water vapor caused by evaporation in that region is soon wafted eastward by the prevailing westerly winds.

So, when we consider Nature's manner of proceeding while working through long geological ages to furnish the materials for building up the lands of the Great Lake basin, it appears that the fresh-water lakes are of recent geological origin and are giving out a larger flow of fresh water during the present low stage of northern ocean water than ever before obtained, as the increase of land from glacial débris during the later cold periods of Quaternary times is more favorable for the storage of rain-fall to supply the lakes with fresh water than the lands built up of earlier geological deposits largely composed of salt and limestone.

It is reported that, according to various government records during a succession of years at various stations along the shores of the lakes, the northern shores are generally rising and the southern shores are slowly sinking below the present level of the lakes. The reason of this apparent movement of the shores of the lakes is because there is less dissolvent material in the make-up of the northern shores than obtains in the southern, the land of the northern shores of the Great Lakes being largely composed of Lauren-

tian materials which are not dissolved by water, while the more solutive southern shores are built up more largely of marine matter, consequently at this age are undergoing a slow process of dissolution. This accords with the beach marks made by the lake waters within the great basin since the latest high stage of northern ocean water.

That portion of the Great Lake basin comprising Lake Ontario and the lands extending eastward from Lake Erie to the eastern boundary rim of the said basin have undergone the same general treatment during the same periods of time that has been carried on in that portion of the basin above Niagara Falls. So it happened that the wide depression in the crust of the earth that extended eastward from Lake Erie existed in early geological times as far back as the Silurian ages. Therefore, during that early time the heavy glaciers of a frigid period attracted the southern ocean waters into the seas of the northern hemisphere in sufficient quantity to submerge the Great Lake basin, and so melted the ice with the warmth of the tropical seas, which flooded all the low lands in the northern hemisphere wherever marine tropical growth of that age can be traced. On the retirement of the submerging ocean waters southward the empounded sea water of the great basin was evaporated, and a heavy layer of salt was deposited in the deepest portions of the basin lying south of Lake Ontario. But, when the sea water was evaporated, there was little storage for rain-fall on the dry beds of limestone and salt during the early geological periods of the low stages of northern ocean water. Therefore, during such times the Great Lake basin was a desolate region. But during the later Quaternary times, the great basin south of Lake Ontario being mostly filled with marine matter deposited during mild periods, the conditions became less favorable for the continuance of their work, while the

cold periods were able to accomplish much through glacial action.

The first important work of a glacial period in that region was the filling of Lake Ontario with Laurentian glaciers. This accomplishment afforded the heavy ice-sheets an unobstructed passage southward across the basin, and so enabled them to overrun the coal measures and petroleum beds of Pennsylvania and West Virginia.

During these geological times the marine deposits of salt and limestone received sufficient covering from glacial débris to fill up that portion of the Great Lake basin above the outlet of Lake Ontario, so the submerging seas during the high stage of northern ocean water were no longer empounded on their retirement to the southern hemisphere. Thus the lands were able, under the later conditions, to store up sufficient rainfall to supply the numerous fresh-water lakes of that interesting region before passing off into Lake Ontario and from thence into the sea through the St. Lawrence River. And it is probable that there may have been an outlet opening into the Mohawk valley.

The wasting of limestone and salt deposits which have been going on ever since there has been sufficient storage of rain-fall to supply the numerous lakes of the basin lying south of Lake Ontario has been the cause of much faulting of the limestone strata through the crushing weight of the Laurentian glaciers that passed over the New York portion of the basin into Pennsylvania during the later Quaternary cold periods. And it was through the crushing and eroding work of these glaciers that the beds of the lakes were formed, while the morainic hills that separate the lakes were caused by glacial action.

The lands of the Great Lake basin, having been largely built up of marine matter which is more or less dissolvable

in fresh water, are slowly returning to the sea from which they came. The water vapor from the ocean, after being wafted by the winds over the Great Lake region and there condensed, is precipitated in rain and snow, and so at length passes into the ground, so that the rain-fall that returns to the sea through the outlets of the great basin carries a portion of the marine matter that so largely composes the substance of its land. Therefore, the solutive strata of the land are slowly diminishing in thickness, and will so continue as long as the conditions that govern this age of the world gradually give way to a period of coldness, which will add a new covering of glacial débris to the lands of the great basin, and also lessen the area of the Great Lakes.

But meanwhile the lessening of the area of the lakes will cause less evaporation, while the enlargement of the lake shores will add to the storage of rain-fall, and so cause a larger flow of water from the outlets of the great basin in the manner we have previously pointed out.

Thus, while we contemplate Nature's methods for building up the lands of the Great Lake basin, it seems wonderful how many different conditions have existed since the earliest salt deposits have taken place. For it appears that there must have been deep basins existing in the crust of the earth previous to the first ice age that glaciated the greater portion of the continents and islands of the globe, while anterior to that time the distribution of the ocean waters must have been largely in the southern hemisphere, as is the case to-day, and the only thing of that time that could largely attract the superior southern ocean waters into the northern hemisphere was the preponderate weight of the glaciers of the great northern continents and islands.

On the breaking up of this early ice period, the high stage of northern ocean water slowly returned to the southern

hemisphere to again augment the southern seas, while the basins of the northern lands empounded the retiring sea waters, which, after being thus separated from the sea, were evaporated by the winds and solar rays, and so formed a deposit of salt. This was at length followed by a period of cold, which accounts for their stratified nature, interposed by beds of clay derived from glacial work, and deposited during the high stage of thermal ocean water following an age of coldness.

Large deposits of salt exist in India, which occur in solid cliffs in the north-east Punjab, which for extent and purity are said to have no rival elsewhere in the world. This great saline deposit goes to prove that during periods of high stages of the sea in the northern hemisphere the salt sea waters were empounded, and, after the retirement of the flooding sea waters into the southern hemisphere, the empounded waters were evaporated, and the salt deposited where it now lies. The deposition of this great mass of salt must have required several geological periods for its completion, because the empounded sea water could deposit only the salt it contained in a single period.

The morainic barriers that confined the sea water along the seaward margin of the Himalaya Mountains were at length removed by the ocean waves during high stages of the sea, and by glacial action during subsequent cold periods, and thus exposing solid cliffs of rock salt. So this great deposit of salt confirms the fact that through a simple natural process all the low lands of India, including the great central plain of the Ganges, were submerged during the high stages of ocean water in the northern hemisphere. The discovery of petroleum in the Punjab, Assam, and Burma, which is associated more or less with salt, affirms the flooding of India during the high stages of northern ocean water, all of

which must have been followed by low stages of ocean water in order to evaporate the confined sea water and so cause a deposit of salt, and the process must have been repeated many times to build up the great salt deposits that exist in Asia, Europe, and North America.

The salt deposits of Louisiana seem to have undergone great denudation from the descriptions that have been given of that region. The lagoon where the salt was deposited through evaporation of sea water must, during the early periods of its formation, have been separated from the Gulf of Mexico by a rim of land which has been removed; while the ancient salt deposit obtains a higher elevation than the surrounding low land. The removal of the basin may have been caused by the dashing waves when the gulf waters stood at a higher sea-level than now. Besides, it was exposed to glacial action during later cold periods, when heavy ice-sheets covered the whole Mississippi valley. The ice, owing to the gentle slope of the land, was slow in its movement, but more active where the heavy ice entered the sea, and therefore was more capable of removing the rim of land that separated this salt basin from the waters of the gulf; and on further consideration it appears that the ridge of land that formed the seaward side of the salt basin was probably a morainic deposit of an earlier glacial period.

The consideration of the causes that have brought about the salt deposits shows plainly that they are of periodical origin, and are present in every order of succession of the earth's crust from the earliest saline deposit to the present time, while the conditions for their existence in the northern hemisphere has required high stages of northern ocean water to flood their basins with sea water, and periods of low stages of water for its evaporation. And, like the coal measures

and petroleum beds, the salt deposits have required many glacial periods for flooding the saline basins with sea water.

Meanwhile the high stages of northern ocean water were favorable for the growth of petroleum beds, while the succeeding dry periods were suitable for the evaporation of sea water, yet at the same time the rain-fall was sufficient for the rank vegetable growth of the coal measures. Still, the deposits above named required no great deformation of the earth's crust except what could be performed by a glacial action during cold periods and such disturbances as are caused to-day by volcanic, marine, and aërial agencies.

But there appear to be various opinions held at this date by geologists respecting the changes that have been wrought on the land surface of the globe during cold periods through glacial action. Some think that glaciers have never been an important geological agent, while others assert that during a late geological epoch ice-sheets covered a large portion of North America, Northern Europe, and Northern Asia; and others admit that two or three ice periods have taken place, and that during the latest ice age Northern Europe and Northern North America were overspread with ice-sheets of great thickness. In New England Mount Washington was overrun with heavy glaciers, while Nantucket and Martha's Vineyard are largely composed of glacial débris.

Professor James Geikie states in his description of glacial deposits in Northern Italy that the deposits from Alpine glaciers of a frigid period "rise out of the plains of Piedmont as steep hills to a height of 1,500 feet and in one place to nearly two thousand feet. Measured along its outer circumference, this great morainic mass is found to have a frontage of fifty miles, while the plain which it encloses extends some fifteen miles from Andrate southward." And it is reported

that there are found on the southern flank of the Jura numerous scattered bowlders, all of which have been carried from the Alps across the intervening plains and left where they now rest. Many contain thousands of cubic feet, and not a few are quite as large as cottages. Such blocks are found on the Jura at a height of no less than 2,000 feet above the Lake of Neuchâtel. The Jura Mountains being formed mostly of limestone, it is easy to distinguish the débris deposited by Alpine glaciers; and from what we can learn of extensive glacial work it appears that intervening plains, lakes, and sounds are so often found separating the source of ancient glaciers from their deposits that their existence becomes almost necessary to represent the general outlines of disturbance performed during an ice period. In consideration of such facts we have been led to believe that the Coast Ranges of California are of glacial origins.

Professor Whitney describes the Coast Ranges of California as being made up of great disturbances which have been brought about within geologically recent times, and this statement we have found so obvious while exploring that region. It appears that the Coast Ranges originated in a different manner from the older Sierras. The western sides of the latter mountains everywhere show the great eroding power of ancient glaciers. In making an estimate of the work performed by the glaciers of that region during many glacial ages, it should be considered that this lofty mountain range lies directly across the path of the prevailing westerly winds that waft the North Pacific water vapors eastward over the continent. Consequently, they were in a position during glacial periods to gather large quantities of snow sufficient to form heavy glaciers superior to any other mountain range situated in the northern hemisphere. Therefore, in the early

geological ages, before the Sierras had undergone great reduction in height and bulk from glacial action, the débris from such action was deposited in the deep waters of the Pacific Ocean; and the ancient channels so caused are still existing beneath the coast waters and abreast the hills bordering the sea. Meanwhile a wide shelf was built up from such glacial drift as was not forced into the deeper sea and from heavy river deposits during the low stages of the northern oceans. Therefore, the shelf so caused during the flooding periods was favorable for the growth of limestone and other marine matter, besides the growth of such aquatic vegetation as was required for petroleum beds. And these deposits during the low stages of North Pacific waters were heavily covered by the detritus brought down from the Sierra high lands by the rapid rivers, and so spread broadcast by their overflowing waters, which furnished good protection against the ice-sheets of a succeeding glacial age. And it is probable that during the lowest stage of northern ocean water considerable sea water may have been evaporated in such shoal basins as may have existed in that region. But at length the Sierra Range was so much reduced in height through glacial action carried on during many glacial periods that the ice-sheets descending from the diminished heights could no longer force their débris out into the deep sea, and so made their immense deposits on the outer edge of the shelf, where they now remain and form the range of hills that now border on the sea.

The Contra-costa Range was the work of glaciers of a later period, when the Sierra Mountains were further reduced. Therefore, the glaciers with diminished force built up with their morainic débris the Contra-costa Range of hills, and it may be said that this range of high hills is the work of more than one ice period, and the same may be said of the range of hills next to the sea. But the islands abreast the coast

are glacial deposits of an earlier date. And it may also be asserted that the islands, although situated several miles from the main land, represent the morainic débris eroded from the deep valleys of the Sierra Range, and the same may be said of the largest Coast Range elevations.

The plain on which the Coast Range hills are deposited was, during high stages of Northern Pacific water in early Tertiary times, the bottom of a shallow sea, which was favorable for the marine growth of petroleum, and during the later glacial periods a portion of the oil derived from the earlier marine growth of submerging seas was still partly preserved in the marine strata of the plain where the morainic hills now rest. Yet it appears that the immense weight of the moraine-bearing glaciers, while moving over the oil strata, caused more or less disruption. So the oil thus set free mingled with the morainic detritus to a considerable extent. Thus the character of the morainic mass seems to have undergone considerable change. So much was this the case that the Coast Ranges in several places have been subject to igneous action, which may have been caused by heat generated from pressure exerted on the interior masses during subsequent dry epochs. And it appears that the conglomerates and bowlders which the Coast Ranges contain have been subjected in a less degree to the same agencies.

While the Coast Range hills were being built up by glacial action, it is not to be supposed that the moraine-bearing glaciers were always in contact with the earth while moving over the low lands. The fact is, the bottom ice was at times frozen solid to the ground floor, and formed a platform of more or less thickness which butted against the glacial débris at the place of deposit. Thus this icy floor was overrun by glaciers from higher elevations, so that a portion of the glacial débris that built up the Coast Range hills was a thousand feet

or more above the ground while being moved from the icy steeps of the Sierras to the coast hills, where they now rest. In this way the higher portion of the Coast Ranges were built up, while the altitude of the Sierra Mountains during such times were considerably higher than their altitude at the present time.

Thus, when we contemplate the great geological disturbances that have taken place in the building up of this region, it seems remarkable that the land has obtained the solidity and quietness it has shown since its settlement by Europeans. So there are reasons for believing that the land will continue to grow in stability because of the long slope extending from the shore out into the deep ocean, which is not the case along the South American shores, where the heavy water waves occur with the earthquakes.

The earthquake region of California is subject to conditions different from any other land on the earth that we know of. The lofty Sierra Nevada Range stretching along its eastern borders is able during the winter season to arrest a large portion of the Pacific Ocean water vapors while on their eastern passage across the continent; and, because of the low temperature encountered on the Sierra heights at such times, they are partly condensed and precipitated, causing a great fall of snow, sufficient to fill the numerous valleys of that region. This vast collection of snow on the return of spring is melted by the heavy periodical rain-fall of that season, so that every rivulet and river is running full of water to empty its contents on the great fluvial plain which extends along the foot of the lofty Sierra Range from Lake Buena Vista northward along the San Joaquin and Sacramento valleys into Colusa County, a distance of about three hundred and fifty miles, with a width covering from ten to thirty miles. Consequently, this great plain during

spring freshets is largely flowed with fresh water that cannot readily find a passage to the sea through the channels of the San Joaquin and Sacramento Rivers. Therefore, the great plain drained by these rivers remains flooded for several weeks, while the large spread of fresh water seeking the sea may have lost a portion of its contents through filtering downward through porous earth to the ancient marine strata, composed of salt deposits and other dissolvable marine matter that was laid down before the Coast Range hills existed, and during later times became exposed to the dissolving properties of fresh water; and so a portion of the solvable structure found its way into the sea.

Therefore, the ancient strata, after having lost a portion of their solidity, were in a condition to give way where heavy morainic hills had rested quietly many years; and, when the shocking event happened, the whole region was more or less disturbed by the sudden collapse of the weakened strata wherever extending, especially along the earthquake rift which marks the line of the greatest disturbance. The land bordering along this line probably covers the heaviest marine formations laid down in that vicinity during the ancient warm periods, it being the line where the Pacific Ocean breakers were favorable for the growth of coral reefs, which are mostly found on the rugged sides of coral-growing shores. Meanwhile, during the early geological periods when the low stages of northern ocean water were lower than now, judging from the presence of saline water in the vicinity of the earthquake rift, large deposits of salt were made through the evaporation of sea water where the ice of glacial periods has, in many instances, left extensive basins on the breaking up of the ice, without outlets to other sources of water, as the Sierra drainage found its way to the sea in less obstructed channels than now obtain. So it was left for high

winds, combined with high ocean tides, to supply the basins with sea water for evaporation until heavy deposits of salt were made; and these deposits subsequently were covered with the débris of a succeeding glacial age, and so formed a part of the crust of the earth. Still, this dissolvable marine strata which lie at the bottom of the earthquake disturbance, although overlaid by the Coast Range hills, may not lie over fifteen hundred feet below the surface of the valleys, and it may be somewhat less. Therefore, a land built up in the manner we have described could not escape being more or less disturbed by earthquakes, which have prevailed for several thousand years during the present period of low-stage northern ocean water.

It may occur to many that, if a low stage of ocean water now obtains in the northern hemisphere, how it happened that sea water could be evaporated in salt basins that now are declared to be many feet below the present sea-level. But we know that coal and salt deposits are reported to occur many feet below the level of the sea in the northern latitudes at this age. The order of succession of the stratified formations appears to show that such is the case. So it appears that the oceans of the globe must necessarily have gradually gained a higher sea-level during each succeeding geological period for the reason that during every frigid period the vast amount of glacial débris moved from the great continents and numerous islands of the globe into the sea must have caused a rise in the sea-level, and the same result must have taken place from the immense growth of limestone and other marine matter on the world-wide reefs and shoals that occur below the sea-level, besides the deposits from the numerous rivers that empty into the sea. So through these natural agencies the seas of the southern hemisphere during their present high stage have less capacity for holding the

ocean waters than they possessed during the earlier ages. Therefore, the deepest coal measures and salt basins are below the sea-level at this age of low stage of ocean water in the northern hemisphere. Still, where the ancient sea floor has not been raised by glacial débris, the oceans have gained in depth in proportion to the rise of the sea-level; and so it happens that, when we trace back to early geological times and find that strata of coal and salt have been laid down in the high temperate northern latitudes below the present level of a low stage of northern ocean water, we are brought to the conclusion that the great oceans of the southern hemisphere have held a larger proportion of the world's waters at a lower sea-level than obtains at this age. Therefore, it seems that during such ancient times, while the northern seas were at a low stage, deposits of salt and other soluble marine matter were laid down on the site where the California earthquakes occur. Yet, when the cause of such land disturbances is considered, it appears that, with the mechanical knowledge attained in building materials, the people will be able to guard against such earthquake disturbances as may occur, and so be able to enjoy the mild and healthy climate of a fertile and beautiful region.

Having given our views regarding the cause of the recent California earthquakes, we will call attention to the causes that have brought about the many earthquakes that have taken place along the Pacific coast of South America since it has been known to Europeans.

When South America, at the perfection of the last frigid age, was covered with ice, the lofty Andean range was burdened with glaciers, while the morainic débris eroded from the Pacific side of the mountains was forced into the ocean and deposited on the steep grades slanting into the deep sea. The glaciers, while entering the sea, pushed their débris

down the steep declivity until the submerged portion of the glacier was broken off because of its buoyancy, and so became an iceberg that was soon floated away by the winds and ocean currents. So the process went on until the breaking up of the ice period. Thus the great morainic masses, eroded from the steep-sided Andes and deposited on a precipitous grade, have from time to time, through a slight earthquake tremor such as all lands are subject to, proved sufficient to cause the morainic mass to move down the steep submerged slope into the lower depths of the sea. The abruption of a great mass of earth from the adjoining land not only gave a shocking disturbance to the lands in the vicinity, but the sudden movement of large masses of earth below the surface of the sea made a great commotion in its waters, causing destructive tidal waves. The effect of such disturbance took place at Arica Aug. 13, 1868, when a tidal wave carried the United States warship "Wateree" a quarter of a mile inland, where she still remains, and it is reported that skeletons of whales and other marine débris have been found twenty feet above the present level of the sea. Such marine relics have been thought to afford ample evidence to prove that the western coast of South America has recently risen above the present level of the sea, but the inundations of land by tidal waves do not prove that the solid lands of the continent have been recently raised above the common level of the sea.

Since 1570 there is said to have been seventy violently destructive earthquakes recorded on the west coast of South America. The roadstead of Callao, where ships now ride at anchor, was, previous to the great earthquake of 1740, the site of the old city of Callao, which during the earthquake was submerged, while the land where the city now stands was swept by tidal waves which dashed over the plain towards Lima. The last named city at that time was greatly injured

by earthquake shocks. The recent earthquake at Jamaica, which partly destroyed the city of Kingston, affords a remarkable instance of the destructiveness of a costal earthquake, which was brought about in the same manner as those we have described in South America.

We know of only one instance of an earthquake occurring from the disruption of Atlantic coast land, which happened during the Charleston earthquake of 1886. The cause of that violent shock may have been brought about by the sinking of the great stone fleet in 1862 on an unstable bottom, composed largely of sand eroded from the Blue Ridge during the last glacial period, and deposited off Charleston Harbor abreast of a deep portion of the Atlantic. The heavy stone fleet bearing with great weight on the morainic mass, it gave way to a slight earthquake shock to gain a firmer position, this disturbance being immediately followed by the collapse of ancient wasted limestone strata which extended inland as far as the earth movements prevailed.

The great earthquake that destroyed Lisbon, and those that have since caused great destruction in Java, Japan, and other countries, were caused by volcanic action when combined with the causes given in our description of South American earthquakes.

Having given a brief explanatory account of the origin of the California Coast Ranges, and the causes that have brought about the earthquakes of that region, and also the main causes that have contributed to bring about the costal earthquakes which we have so largely attributed to glacial action, it will be seen that we favor Professor Louis Agassiz' views on glaciation, who after his wide researches in South America believes that "the red soil and the immediately underlying beds in Southern Brazil and in the valley of

the Amazon are true glacial formations," and infers that similar beds which are spread over an enormous area in South America have been formed under similar conditions. Professor Agassiz, who was the first to be convinced of the glaciation of tropical South America, also reports that, while exploring the Amazon valley, he found morainic hills supporting bowlders that had been transported by glaciers from the distant Andean region. This shows that during the culmination of the glacial period the great Amazon valley was heavily glaciated. The enormous extent and thickness of the glacier that filled the great valley must have been equal to any of the glaciers existing at the perfection of the ice age, while the whole region was raised above the present sea-level because of the shrinkage of the ocean water at the equator, while supplying the ice-sheets that burdened the great continents and islands of the globe. The great depth of the keel of the great glacier that moved from the Andean region down the Amazon valley for hundreds of miles, to enter the deep waters of the Atlantic Ocean, must have formed one of the deepest and largest canyons on the globe. This is proved by the great depth of the river hundreds of miles from its mouth at the present time, although the channel is partly filled by the fluvial deposits that have settled in its depths since the breaking up of the ice age.

The reason why the tropical zone on the western continent was so heavily glaciated was because of the shortness of the equatorial stream of the Atlantic and its wide exposure to the Arctic and Antarctic Seas. The Arctic Ocean currents were crowded with the icebergs and ice-floes of glaciated Siberia, Northern North America, and Greenland, and besides the Atlantic received the ice of the glaciated lands of Eastern North America and Western Europe.

The South African current also carried large volumes of antarctic water into the equatorial latitudes. Meanwhile the convective currents were carrying in their undercurrents the ice-cold waters of the high latitudes into the tropical zone. At the same time the tropical waters of the Eastern Pacific along the American coast were crowded with icebergs that were floated down the north-west coast from Alaska and the glaciated shores of British America, United States, and Mexico.

The cold Peruvian current that moves down the western coast of South America from the high southern latitudes currented the many icebergs that were launched from the glaciated Andean range, as far north as the Galapagos Islands, so the equatorial sea in that region was crowded with icebergs. Thus it happened that the western continent was surrounded by seas strewed with ice.

The meeting of the British Association for the Advancement of Science, September, 1895, was reported in *Science*, October 18, where mention is made of an interesting paper by Mr. R. B. White, in which he described a number of glacial deposits in the Republic of Colombia in the equatorial latitudes. He spoke of moraines forming veritable mountains, immense thicknesses of bowlder clay, beds of loess, valleys scooped and terraced, monstrous erratics, and traces of avalanches. The drawings he has made of glacial work in that region are very interesting.

In *Science*, Nov. 17, 1893, Mr. J. Crawford published a summary of his discoveries in Nicaragua during ten months of nearly continuous exploration since August, 1892. The author of this report says that the numerous eroded mountain ridges and lateral terminal moraines of that tropical region give unquestionable evidence of a former existence of a glacial epoch which covered an area of several thousand

square miles with glacial ice. The ice-sheet covered a large part of the existing narrow divide of land, containing about forty-eight thousand square miles, between the Pacific and the Caribbean Sea.

It is reported that the higher mountain ranges of Mexico are granites, which seem also to form the foundation of the plateaus, and it appears that from the Colorado plateau southward through the Northern States of Mexico that the deposits of limestone and salt are the remains from the marine growth of thermal seas that submerged the plateau which has been subsequently overrun by the ice of later glacial periods. During the early geological ages, probably the most efficient work in marine growth was accomplished during the Cretaceous periods in high stages of northern ocean waters. It may have made some additions as late as Tertiary times, when a high stage of water would permit, but the upbuilding was slow, because the ice-sheets of every intervening glacial period caused great denudation of the marine growth, so the remaining elevations of the limestone rocks have been wonderfully wrinkled into folds and depressed by the heavy ice-sheets, which have also caused much faulting of the lands. But during the mild periods of Cretaceous times its marine growth was probably rapid during the high stages of Gulf of Mexico water. And during the Tertiary periods its marine growth during high stages of water was probably equal to its denudation, but during the intervening glacial periods of Quaternary times it has lost about one thousand feet of its earlier marine growth by denudation. The rise of sea-level during high stages of ocean water in that region may have obtained about seven thousand feet above the present sea-level of the Pacific and Gulf of Mexico. These high stages of northern ocean water must have submerged the greater portion of Central America, so its highest

lands were converted to groups of islands, which showed the old boundaries of the Pacific Ocean and Caribbean Sea.

Professor Alexander Agassiz, after his researches in the Pacific and Caribbean Sea, has maintained that their waters have been united. And it was during such high stages of northern ocean water that the Salt Lake basin in the latitude of 42° north was flooded with sea water, which accounts for the saltness of its waters to-day. The highest mountains of that region are reported to bear the marks of ancient beaches. Thus it appears that the highest stages of northern ocean waters during such periods must have obtained about sixteen thousand feet above the present sea-level at the north pole. This high stage of northern ocean water caused a great reduction of land in the northern hemisphere.

The whole of North America was submerged except the elevated land areas of the Rocky Mountains, which fortunately extended across the northern-westerly wind-belt, and, with the exception of the narrow Sierra Nevada Range and the high ranges of Alaska and the high mountain regions of Mexico and Central America, the whole of the remaining portion of the continent of North America was below the level of the ocean. Asia was reduced more than one-half in its land areas, while Europe lost more than seven-eighths of its land areas during the high stages of the northern oceans. And at the same time Northern Africa above the latitude of 1° north lost more than one-half of its territory by submergence. So it seems that the southern hemisphere probably possessed a far larger area of land than the northern hemisphere on the breaking up of a glacial period.

Thus all the great changes in the geography of the earth were brought about by the heavy ice-sheets which gathered on the northern continents and islands during a glacial age, and so caused the earth's centre of attraction to move

northward about two and one-half nautical miles, or one-sixteenth of an inch when measured on a globe sixteen feet in diameter, which would cause a rise of water at the north pole about sixteen thousand feet above the present sea-level. Meanwhile the decrease of ocean water in the southern polar latitudes would take place accordingly. With such conditions the Cape Horn channel would be closed, and South America united to the antarctic continent, and New Zealand with its emerged southern lands would also be united to the antarctic lands. Such arrangements would effectually break up the independent circulation of the Antarctic Ocean, and so cause conditions that were favorable for the diffusion of the warmth that the earth derives from the sun.

For at such times the lands of the hemispheres were so arranged that the great prevailing winds were able to move the vast waters of the tropical zone into the temperate and polar seas in sufficient quantities to cause a mild climate even in the polar latitudes.

For, as we have previously explained, with the Cape Horn channel closed, the strong westerly winds would be sure to drift the surface waters of the South Atlantic away from the south-eastern shores of South America over into the Southern Indian Ocean, and so cause a low sea-level, which would attract the tropical waters from the high sea-level abreast Brazil and the tropical waters of the Agulhas current from the high level of the tropical Indian Ocean into the south-western latitudes of that ocean. Meanwhile the united islands of Australia and the more important extension of land from the emerged islands south of New Zealand, during a low stage of southern ocean water a continuous land, would be extended as far southward as the antarctic land. But the deepest water reported

by the "Discovery" was 2,500 and 2,300 fathoms, respectively, while the deepest sounding of the Cape Horn channel gave 2,184 fathoms. But it should be considered that the Cape Horn channel, while the glacial period was nearing perfection, was in a region of great snow-fall and heavy glaciated lands,—namely, South America, Falkland Islands, South Georgia, Graham Land, etc.,—which would have a tendency to cause the bottom of the Cape Horn channel and the bottom of the New Zealand waters to be raised above the sea-level about the same time, and thus be united to the antarctic shores. With this accomplishment the strong westerly winds of these latitudes would drift the surface waters of the South Pacific from the connected land, and so cause the tropical waters of the Western Pacific to be strongly attracted to the low sea-level to the leeward of the said lands, and so cause a vast volume of tropical water to enter the antarctic seas. And on further consideration we find that it was necessary that the waters of the Cape Horn channel and the sea between New Zealand and the antarctic lands should be deep, in order to bring an ice period to perfection, and it was also necessary that the bottom of the sea south of New Zealand and the bottom of the Cape Horn channel should rise above the sea-level about the same time. And it appears that another important provision was brought about while shoaling the southern oceans, in order to connect the southern lands. For, while the remaining southern ocean waters were made shallow, it made the strong prevailing westerly winds much more effective for causing low sea-levels on the South-western Atlantic and South-western Pacific than could be obtained on deeper seas.

And, while we contemplate the subject, it appears wonderful that the oceans and lands in connection with the great

prevailing winds are so arranged that they have been able to cause long periodical ages of coldness and mildness.

There is another important natural provision that is to be considered in the requirements for bringing about the climatic changes necessary for the progression of the periodical ages, and that is the saltness of the ocean. For without this provision the circulation of its waters could not be carried out with the present arrangement of sea and land, because a sea of fresh water would congeal when exposed to the cold of a glacial age. But it happens that, with the increase of glaciers, the sea which supplies the water to form the glaciers, also, at the same time increases in saltness which prevents its waters from congealing, and so enables them to circulate through a glacial age.

In my earlier publications I thought that the Cape Horn channel may have been filled with glaciers while in a shrunken condition, as glacial ice was indestructible in a sea possessing a temperature below the freezing-point of fresh water. But I now think that the ice-sheets that collected on the northern continents possessed ample weight to attract the south seas northward sufficient to raise the bottom of the Cape Horn channel above the sea-level of that latitude. The reason why I think this was accomplished is because of the elevated position of a portion of the salt beds and other marine deposits in Mexico and the traces of ancient beaches in the Rocky Mountain region.

The fact is we often fail, while viewing some vast or ponderous work performed by natural agencies, to comprehend the diminutiveness of such work when compared with the immense natural forces employed and the length of time consumed while the work was progressing.

The perfecting of a glacial period was reached when the lands of New Zealand and South America were connected

with the antarctic shores. But it required considerable time before the melting of the ice could make much progress. Meanwhile the waters of the great equatorial stream of the Pacific and Indian Oceans embraced two-thirds of the circumference of the earth in the tropical latitudes, and were largely excluded from the coldness of the Arctic Ocean, and also far removed from the icy antarctic seas. Still, this vast stream of tropical water was greatly cooled by the numerous icebergs launched into the Eastern Pacific by the glaciers from the North American and South American coasts. So the great stream moved from the American shores to cross the Pacific with a numerous fleet of icebergs. But, while on its western movement, under a tropical sun the ice was gradually melted before reaching the middle longitudes of the Pacific, while the trade winds blew in the same direction as now for the reason that the tropical oceans have always obtained a higher temperature on their western sides than on their eastern sides. So the great tropical stream with its increased temperature sent its side-currents into the southern and northern latitudes the same as to-day, but lacking sufficient warmth to prevent Japan and New Zealand from being glaciated, while the snow line obtained a low elevation on the high lands of the East India Islands. Still, the great equatorial stream, while on its way into and across the tropical Indian Ocean, must have gained sufficient warmth to protect from the coldness of that age the vegetable and animal life within its influence, which included the several races of mankind that dwelt on the East India Islands, Northern Australia, and along the southern coasts of Asia and the tropical coast of East Africa.

The southern coasts of Asia were subjected to great changes during the ice ages. The great plain of India was overrun with glaciers from the Himalayan slopes, and on the breaking

up of the ice age was flowed by the sea, the high lands of the peninsula being reduced to a group of islands, which with the island of Ceylon were probably inhabited during the glacial period. The aquatic animals that now exist in great numbers along the shores of the arctic and antarctic latitudes probably were numerous along the southern coasts of Asia during the ice ages, and so afforded plentiful supplies of aquatic food, and edible vegetables were also obtained for the inhabitants.

But there was one important thing that marine life had to endure besides the coldness of the sea during a freezing age, for with the great increase of ice there must have been a corresponding increase in the saltness of the sea, as we have previously pointed out. But the increase of the saltness of the ocean was necessarily very slow, so there was time for a large portion of the fauna and flora of the sea to become inured to the increasing coldness and saltness of the ocean waters, yet meanwhile it seems that many species of marine life were destroyed during the perfection of a glacial age.

Moreover, one of the wonderful things in Nature's arrangements, according to geological records, was the simple methods employed to melt the heavy ice-sheets of a glacial age from the continents of the earth with the same amount of solar heat that was attained day after day during the vast accumulation of the ice. But the provision laid out for the accomplishment of this gigantic work made it possible when a low stage of southern ocean water connected the islands of New Zealand and Southern South America with the antarctic lands. With this simple arrangement the great prevailing winds of the southern-westerly wind-belt were afforded ample opportunity for causing vast low sea-levels to the leeward of the newly made connecting lands. And, to facilitate the work of the winds, the low stage of southern ocean water enabled

the winds to obtain greater effect for causing low sea-levels than could be effected on deeper waters.

The creation of land connecting South America and New Zealand with the antarctic lands was regular periodical work, which has been brought about many times since the first salt deposits and coal seams were laid down in the primary ages. But in my long marine study I was slow to fully comprehend it, as will be noticed in my earlier publications, but on further consideration I found that an ice-period could not be broken up unless the independent circulation of the ocean waters of the high southern latitudes, which was the main cause of the growth of a glacial age, was destroyed, and that the arrangements for performing a work so vast must be complete, and that an ice period would go on until such arrangements were brought about. Persons interested in this matter will notice that the great circular currents of the South Pacific and South Atlantic oceans are so situated in their vast movements that they would give their whole force and volume while acting with the great prevailing winds and convective currents to send their tropical waters from their high sea-levels to the great low sea-level caused by the westerly winds drifting the surface waters of the sea away from the lands we have described as uniting South America and New Zealand to the antarctic shores. And it seems that the combined action and harmony of the several agencies employed shows a remarkable providence of Nature for moving the tropical waters of the South Pacific and South Atlantic into the antarctic seas, and so carry out the plans of a controlling power.

According to the report of the Belgian Antarctic Expedition the depth of the Cape Horn channel was sounded from Staten Island to the South Shetland Islands. After passing over a narrow marine shelf south of Staten Island, the lead

dropped suddenly to 2,183 fathoms. The bed then rose gradually in an easy slope to the South Shetland Islands. So it seems that the lowering of the sea-level in the southern polar latitudes 16,000 feet would be ample to raise the Cape Horn channel above the sea-level. Still, it may have required a somewhat greater reduction of southern ocean water for its accomplishment. At the present time we have the soundings taken by the "Discovery," which we have previously given, of the deep waters that separate New Zealand from the antarctic lands. And it is generally supposed by those who have given these regions much study that South America, Australia, New Zealand, and the antarctic lands have been united during low stages of southern ocean water.

The further we consider the arrangements of lands and seas in connection with the great prevailing winds, the more we are confirmed in the belief that the climatic conditions of the earth were intended to be periodical. For instance, it required considerable study to find out where a sufficient supply of heat could be furnished to melt the heavy ice from the northern continents and islands. The equatorial stream of the Atlantic of this date passes over about four thousand miles of longitude north of the equator, while the length of the stream south of the equator from Africa to Brazil is about one-third less. This portion of the stream would not possess sufficient heat to melt the antarctic ice of the South Atlantic, even with the Cape Horn channel closed. And the northern portion of the stream would be still less able to thaw out the vast spread of glacial ice that burdened the lands of North America, Europe, and Northern Asia. But, strange as it may seem, ample provision was made for this enormous work, for it appears that the preponderate northern ice-sheets that

covered the northern continents and islands had grown to be the cause of their destruction for the reason that their burdensome weight had at length been able to move the earth's centre of attraction northward about sixteen thousand feet, which would be approximate to one-sixteenth of an inch when represented on a globe sixteen feet in diameter. This seemingly slight change in the earth's centre of attraction, which would raise the sea-level at the north pole about sixteen thousand feet, would also at the same time raise the sea-level above the great Sahara Desert. Therefore, that wide region would be flowed mostly by tropical water from the high sea-level of the great equatorial stream of the Pacific and Indian Oceans. This tropical water would pass through the Red Sea, and when the northern glaciers obtained sufficient weight to raise the sea-level of that sea, and so cause its waters to flow into Africa, they would not possess sufficient heat to quickly subdue the ice and coldness of that vast region. But at the perfection of the ice period, when New Zealand and South America became united to the antarctic shores, the raised sea-level of the enlarged Red Sea must have caused a great flow of tropical Indian Ocean water to enter the wide Sahara region and flood its lands. So it appears that this vast shallow tropical sea, with a surface area larger than the Arctic Ocean of to-day, was enabled to spread out where it would not be exposed to the chilling under-currents that flow from the deep arctic and antarctic seas into the deep tropical oceans of to-day. Therefore, the waters of the Sahara Sea, while exposed to a torrid sun, probably at length obtained a temperature above 100° F. while being slowly drifted westward by warm easterly winds, thus adding heat and volume to the equatorial stream of the Atlantic, and so swelling the great high sea-levels abreast the coast

of Brazil and the Caribbean Sea, thus affording a plentiful supply of warm sea water for the Brazil current while melting the ice-sheets from the South Atlantic and its shores. Meanwhile the Carribbean Sea and enlarged Gulf of Mexico and enlarged Arctic Ocean were abundantly supplied with thermal water sufficient to subdue the glaciers of North America, Europe, and Asia, in the manner explained in the preceding pages.

It may be said in regard to the submergence of mountain lands during high stages of ocean water in the northern hemisphere that there is an absence of marine remains to be found on the slopes of such mountains, as far as is known. But this cannot be said of Mexico, where salt deposits and limestone abound, while further north Salt Lake basin affords evidence of having been submerged by the sea, and the neighboring mountains are reported to show traces of ancient beaches many hundred feet above the level of the lake.

Professor William P. Blake, University of Arizona, published in *Science* of June 21, 1907, his views, derived from extensive research, on "The Flanking Detrital Slopes of the Mountains of the South-western United States," wherein he writes that "the flanking mountain slopes are most distinctly developed in the great basin of Nevada, and a fine example of a flanking slope is found on the north side of San Bernardino Mountain in California, extending from the Cajon Pass to the Mohave River, which shows the operation of a widely distributing or levelling, which, it would appear, could not have been other than tides, waves, and currents of the ocean during submergence of the land." He also writes that in the region of Tucson, Ariz., there are fine examples of long slopes of great regularity flanking the Santa Catalina Mountains, the Santa Ritas, and the

Sierritas. In the Huachuca Mountains the upper margin of the slopes is higher, being nearer the five thousand foot contour.

From the description given of this region it appears that the mountains have been carved out of an ancient high plain, the denuding work having been mostly performed by the action of glaciers during many frigid periods, the deepest depressions having been obtained on such portions of the plain as happened to be the most easy to give way to glacial action, while the more hardened places were more enduring, and so were able to resist the heavy ice which was always attracted to the places that were the most easily affected by glacial action, and so were able to excavate the valleys until the heavy ice-sheets were overflowed by the inundating high stage of the northern ocean waters, which slowly melted the ice, and in a less degree wasted the land with the constant disturbance of ocean currents, tides, and wave action.

But the northern ocean waters that flowed the lands in the South-western United States west of the Rocky Mountains were not favorable for the growth of marine life, as they approached the Pacific coast from the north-west, and had been the rounds of the North Pacific, having left the tropical zone south-east of Japan, from which the great stream takes its name, and, while moving into the high northern latitudes, its waters were drifted by the prevailing westerly winds over against the north-west coast of North America, and from thence by a favorable north-westerly wind along the Pacific coast of the United States. Therefore, the Pacific waters were many degrees colder than the Gulf of Mexico waters of the same latitude. Consequently, the high stages of northern ocean waters have not been favorable for the development of marine life on the western

side of the Rocky Mountains during Quaternary times. Yet during the early periodical ages it appears that deposits of salt and petroleum were obtained through changes of sea-level along the Pacific coast of the United States, and on further consideration I am led to believe that the ice periods of Post-tertiary times and the intervening mild periods were of shorter duration than the cold and mild periods of the earlier geological ages. For it is probable that the Cape Horn channel has been made more shallow by the débris from the glaciers of the early ice ages. And the same result may have been accomplished by the antarctic glaciers on the wide sea south of New Zealand. But it is impossible to find out at this date how many islands have been worn down by the waves and ice action below the present ocean level sufficient to lessen the depth of the sea in that region.

Such a performance would stop the further independent circulation of the southern oceans when nearing the perfection of an ice age, and so prevent an additional accumulation of ice from forming and thus hasten the return of a mild period. Still, with the shortening of the ice period there would be less tropical water and less time required to break up the ice of the later geological period than was necessary during the earlier geological age, when a greater gathering of ice in the northern hemisphere was collected, and a higher stage of northern ocean water was required to subdue the ice. Therefore, the early geological periods were able to perform greater glacial work and also to make larger marine deposits than the shorter climatic periods of late Quaternary times. In fact, the northern glacial drift of the northern temperate latitudes is destitute of limestone deposits such as obtained in the warm submerging seas that followed the earlier ice ages. The glacial drift of New

England and the glacial clay and sand of the Lafayette formation of the last glacial age seem to be destitute of a marine covering, which shows that the warm sea that subdued the glaciers of the last ice period left no deposits of thermal ocean life. This seems to be the case on the plateaus of Mexico, where during the early geological ages heavy deposits of limestone were made on the granite foundations of the plateaus which rise over six thousand feet above the sea-level of to-day. Yet during the high stages of northern ocean water the limestone deposit must have gained a thickness of one thousand feet during Cretaceous times. This is shown by the hardened deposits of marine growth that remain after the denudation caused by the glaciers of the Post-tertiary ice periods, which have been very destructive to the marine deposits of the early geological ages in the Northern States of Mexico.

In Chihuahua the hardened varieties of limestone that have partly withstood the erosion of the Quaternary ice periods are reported to rise several hundred feet above the granitic plateau in the southern part of the State. Thus it appears that the high stage of northern ocean water in that region must have been about seven thousand feet above the present sea-level.

Meanwhile the rise of sea water at that time must have flowed the Sahara Desert lying in the same latitude, and the great plain of India was also submerged.

Such an increase in the rise of northern ocean water, beginning at the equator, must have caused a rise of sea-level at the north pole about sixteen thousand feet. Therefore, the lowering of sea-level in the latitude of 60° south probably obtained about fifteen thousand feet. Still, it may have required a somewhat lower stage of water than we have named to bring the ocean floor above the level of the

sea, although the bottom of the sea on which the islands south of New Zealand rest was raised well above the sea at that time.

Thus, when the connection of South America and New Zealand with the antarctic land was made, the united lands of New Zealand extended northward to its northernmost capes of to-day.

This arrangement was necessary in order that the circulation of thermal water heated by a tropical sun should be able to enter the high latitudes of the southern seas in ample volume to subdue the ice of a glacial age in the manner we have explained in the preceding pages.

In fact, it appears that there was no other way possible, with the peculiar arrangement of lands and seas in connection with the great prevailing winds, to bring about the great changes of climate and sea-level to which the earth has been subject since the earliest geologic deposits were made.

Thus, while we consider the matter, it seems astonishing to the searching mind, while tracing out the ample provisions that the ruling power of Nature has made to bring about the geological climates and changing sea-levels, to find them occupying the most secluded parts of the earth where vast inclement lands and seas abound or wide desert wastes of rocks and sand prevail.

The changes of the earth's centre of attraction and sea-level have not been wholly latitudinal, for it appears that, during periods when the northern ocean waters were at a high stage and the low lands of Europe and Northern Asia were submerged, the westerly winds drifted great quantities of surface water from the North Atlantic into the western Pacific Ocean, which could not be returned by gravity, because the earth's centre of attraction was changed according to the weight of water moved from the western hemisphere

into the eastern hemisphere. This longitudinal change in the earth's centre of attraction and sea-level was very small when compared with the great changes of the earth's centre of attraction and sea-level caused by a glacial age. Yet it was ample to submerge the low lands of Borneo sufficient for the growth of petroleum beds and also cause the flooding of the rank low-land vegetation where seams of coal are found in connection with deposits of limestone. So it appears that after the retirement of the high stage of northern ocean water was accomplished, and the wide connection of the North Atlantic with the North-western Pacific cut off by the emerged lands of Northern Asia, still the work of the longitudinal high sea-level can be traced in the Borneo petroleum beds and remnants of other marine matter in that equatorial region.

While considering the manner in which great climatic changes have been brought about in the high southern latitudes, it is well to bear in mind what I have before pointed out, that the warm waters of the tropical oceans cannot at this date penetrate far into the southern seas on account of their separate circulation. For instance, the tropical waters of the high ocean levels which lie abreast Brazil in the Atlantic and the east coast of Africa in the Indian Ocean, and abreast Australia in the tropical Pacific, are not attracted into the higher latitudes of the southern seas in full volume, because the surface waters of the latter seas are drifted by the strong prevailing westerly winds from west to east constantly around the globe. Therefore, the tropical waters on reaching the latitudes where this great drift-current prevails are turned away, and so largely prevented from entering the cold southern seas. Consequently, the temperature of the southern seas is slowly lowering, and this falling temperature will continue until an age of coldness is brought about, and so proceed

until the great continents of the northern hemisphere are sufficiently loaded with glaciers to attract a portion of the southern ocean waters into the northern latitudes sufficient to cause the bottom of the Cape Horn channel and the bottom of the sea south of New Zealand to be brought above the sea-level, and thus cause South America and New Zealand to be connected with the antarctic land, thus entirely breaking up the independent circulation of the southern seas. Therefore, the prevailing westerly wind, instead of drifting the surface waters of the southern seas around the globe, would drift their surface waters away from the land connecting South America and New Zealand, and so causing low sea-levels that would attract the tropical waters of the Western Pacific and South Atlantic Oceans well into the seas of the high southern latitudes in the manner set forth in the preceding pages.

The great currents of the southern oceans, owing to the prevailing winds and convective currents, move in a general way in a vast circle, their eastern quadrants being drifted northward by offshoots from the great southern drift-current which turns northward along the coast of Peru in the Pacific and along the south-west coast of Africa in the Atlantic and South-western Australia in the Indian Ocean, while the northern portion of these great currents are drifted eastward by the trade winds, where they gain their greatest heat; while on the western sides of the oceans the great currents are moved southward by monsoons and convective currents, which are assisted by the low sea-levels caused by the westerly winds drifting the surface waters of the sea away from the shores of islands and continents, and at the same time the strong westerly winds are forcing a large portion of the drifting southern ocean waters around the globe. Thus it will be seen that, when the independent

circulation of the southern ocean is broken by uniting South America and New Zealand to the antarctic lands, the great prevailing winds of the southern-westerly wind-belt would drift the surface waters of the sea away from the uniting lands and cause wide low sea-levels, which would attract a great volume of tropical water from the high levels of the south-western tropical seas of the Pacific and Atlantic Oceans well into the high latitudes of the southern polar seas. Thus it will be seen that a mild climate would prevail in the southern hemisphere as long as the low stage of southern ocean water continued. Meanwhile the necessary high stage of northern ocean water caused by the attraction of northern glaciers would also cause conditions that would bring about a mild climate in every region of the northern hemisphere.

As the rise of northern ocean water would be about sixteen thousand feet at the pole, it would flow all the low lands of North America, Europe, and Asia, and a large portion of Northern Africa would be submerged by the sea. In Asia the vast plains of India and Siberia would be flowed. In Europe the highest Alps were probably the only land not entirely submerged.

In North America the tallest mountains in Central America and Mexico were the only land that appeared above the sea, while north of Mexico the Sierra Nevada and Rocky Mountains were the only lands to separate the North Atlantic from the North Pacific Ocean, and it is doubtful if the Rocky Mountain range, after the glaciers of the last ice age were subdued, was able to entirely separate the Atlantic water from the Pacific along the whole length of the range, and this may have been the reason why there are remnants of the latest ice periods still to be found buried beneath glacial débris in Alaska and North-western British America.

These lands were situated in a cold region which renders